100 GW ELECTRON BEAM GENERATOR

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ABSTRACT

A 100 GW electron beam generator consisting of an LC generator, a coaxial water line, an 8-channel output switch, and a field emission diode are described. This generator, directed toward the support of research activities, is capable of producing up to 6 kJ of beam energy with particle energies in the range of 100 to 500 keV.

Introduction

Electron accelerators producing intense pulses of electrons with electron energies under 1 MeV and currents in the hundreds of kiloamps have found a variety of applications.[1] The Neptune accelerator designed and built by the Ion Physics Corporation will be described here. Its basic operating parameters are:

Maximum beam energy: 6 kJ
Pulse width: 80 nsec FWHM
Risetime: 25 nsec (10%-90%)
Maximum beam power: ~ 100 GW peak
Maximum beam current: 300 kA peak

Due to the recent interest in intense pulsed ion beams for controlled fusion, the last section discusses the necessary steps in converting from a negative output to a positive output pulse.

Neptune E-beam Accelerator

The overall design of the Neptune accelerator is shown in Figure 1. Upon firing of the LC generator, which erects in approximately 5 μ sec, closure of the transfer switch is initiated and the energy is transferred in approximately 350 nsec from the LC generator to a 1.5 Ω coaxial water line. At peak voltage on the coaxial line a triggered eight-channel output switch connects the coaxial line to a 1.5 to 1 ohm transformer and field emission diode.

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A I 00 GW electron beam generator consisting of an LC generator, a coaxial water line, an 8-channel output switch, and a field emission diode are described. This generator, directed toward the support of research activities, is capable of producing up to 6 kJ of beam energy with particle energies in the range of 100 to 5 00 keV.

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LC Generator

The LC generator is described in some detail in a paper presented at the 13th Symposium on Electron, Ion, and Photon Beam Technology[2]. The total erected capacitance of the 20 x 430 nF capacitors is 21.5 nF. The maximum stored energy is 18 kJ at 65 kV charging voltage.

Coaxial Water Line and 8-channel Output Switch

The 1.5 ohm coaxial water line in conjunction with the low inductance output switch converts the slow energy of the LC generator into a fast and well defined burst of energy and launches it through a transformer section toward the diode. The maximum line voltage is approximately 1 MV. The line impedance of 1.5 ohms was chosen with regard to minimum risetime for a given outside diameter of the line and given diode impedance.

The output switch is the most important element of the generator. It must be of very low inductance to provide a fast pulse risetime and maximum energy transfer. The design chosen was an 8-channel high pressure gas switch as shown in Figure 2. All eight channels were separately and simultaneously triggered via 8 RG-17 cables from a common trigger generator (IPC - Mini Marx™ MMM 4-5-8). The switch inductance was calculated to be less than 25 nH, a value which was also experimentally demonstrated. Reliable closure of the channels was verified by the high degree of repeatability of the risetime and a correspondingly longer risetime if the channel number was intentionally reduced to 1 or 2 cables. Each of the trigger cables had a 50 ohm series resistor to eliminate voltage reversal and ringing.

The switch design was greatly helped by the use of a computer program[3] which made it possible to grade the electrical field along the bushing in such a way that the triple points were somewhat stress relieved. The maximum stress was only 30% higher than the average stress. The great difference in dielectric number between water (80) and most solid dielectrics can be beneficially used in stress grading as indicated by the field shaping dielectric in Figure 2, which pulled the field lines toward the diode side of the switch.

The trigger generator and cables in Figure 1 also illustrate the trigger isolation. The output pulse is timewise isolated as long as the length of the cables between trigger generator and output switch is in excess of the pulse width. In this case the short circuit formed by the trigger cables is sensed only after the pulse has passed.

The switch comprises brass electrodes, a crosslinked poly styrene envelope, aluminum endplates, and delrin tie rods. The switch medium is generally SF_6 at 10 atmospheres or a mixture of SF_6 and N_2

Diode and Diode Interface

The water/vacuum interface between the transformer and diode is made of a smooth annular lucite segment. The thickness of the interface as well as the diode chamber was kept very small to minimize inductance. The inductance of the transition is estimated at 15 nH, thus allowing an overall output pulse risetime of approximately 25 nsec. The design of the transition section was based on a system first tested on Gamble I at NRL[4]. It is designed to withstand more than 1 MV without breakdown. The anode-cathode geometry was designed to allow maximum flexibility. Commonly, the diode comprises a graphite cylinder as cathode and an aluminized mylar as anode. Since the mylar anode must be replaced after every shot it is housed in a hinged door as shown in Figure 3.

Triggering, Jitter, and Diagnostics

All switches are triggered, as shown in Figure 4, thereby allowing maximum control of the output signal. As a consequence of this and the very low jitter associated with each of the trigger generators and switches, a very high degree of pulse to pulse reproducibility can be obtained. An amplitude variation of less than 1% was observed. Firing all the switches at voltage-crest also produces high energy transfer from the LC generator to the diode. A typical transfer ratio is on the order of 30 to 40% and could be further improved by reducing the damping in the LC generator.

A typical jitter between command signal and output pulse is on the order of 5 nsec rms. A smaller jitter can however be obtained if the reference signal is taken from a location further along the time sequence. For example, the jitter between the output signal of the second trigger generator and the e-beam pulse is on the order of 3 nsec rms, while the jitter between the output of the last trigger generator and the e-beam pulse is less than 1 nsec rms.

The diagnostic tools of the accelerator consist of a resistive divider for the LC generator and capacitive dividers[5] for the coaxial water line, the transformer input, and the transformer output. The diode current is measured with both a 1.25×10^{-2} mm thick S. S. shunt across the lucite interface and a Rogowski coil in the anode door. The diode voltage is obtained by the signal from the capacitive divider at the transformer output and an appropriate L di/dt correction. Typical diode characteristics for electron beam generation have been discussed in some detail by R. Wenstrup[6].

Prepulse

The Neptune accelerator has a very low prepulse due to the combined effects of 1.) a low coupling capacitance in the output switch, 2.) a relatively large shunt capacitance of the transformer to ground, and 3.) the use of timewise trigger isolation. Since the charging time of the coaxial line is much longer than the electrical length of the trigger cables,

the trigger cables act as a shunt impedance during the charging of the line. The exact value of the prepulse was estimated to be less than 1%.

Polarity Reversal and Ion Beam Production

In recent months the production of intense positive ion beam for controlled fusion has become the subject of considerable interest[1]. Consequently one of our Neptune accelerators was adapted toward the production of intense bursts of ions. In particular we have changed the polarity of the output pulse from negative to positive.

In converting from a negative to a positive output it is important to consider:

a) the reduced breakdown strength of water for positive polarity,

b) the reduced flashover strength of the lucite interface between transformer and diode, and

c) the polarity of the trigger signal for optimal jitter and switching range.

In the case of Neptune, the electrical stress on the pulse line was originally very conservatively designed and thus allowed trouble-free operation in excess of 1 MV for positive polarity. The breakdown strength at the area where the trigger cables penetrate the inner cylinder of the transformer was increased by the use of a solid dielectric cylinder around the cables. The design of the diode interface was again quite conservative; consequently, the interface easily withstood a stress of 750 kV. The 750 kV was not a real limit, but corresponds only to the maximum voltage applied. With regard to the trigger polarity, all the trigger signals were reversed.

After successfully reversing the pulse polarity this Neptune accelerator was then shipped to the Laboratory of Plasma Studies at Cornell University, where the production of ion beams with this accelerator was very quickly demonstrated[7]. For a pinched diode configuration such as the one shown in Figure 5, ion currents up to 12 kA at current densities in excess of 1 kA/cm^2 were produced. By the use of a magnetically insulated diode similar to the one shown in reference 8, proton currents in excess of 100 kA at energies on the order of 300 keV were produced.

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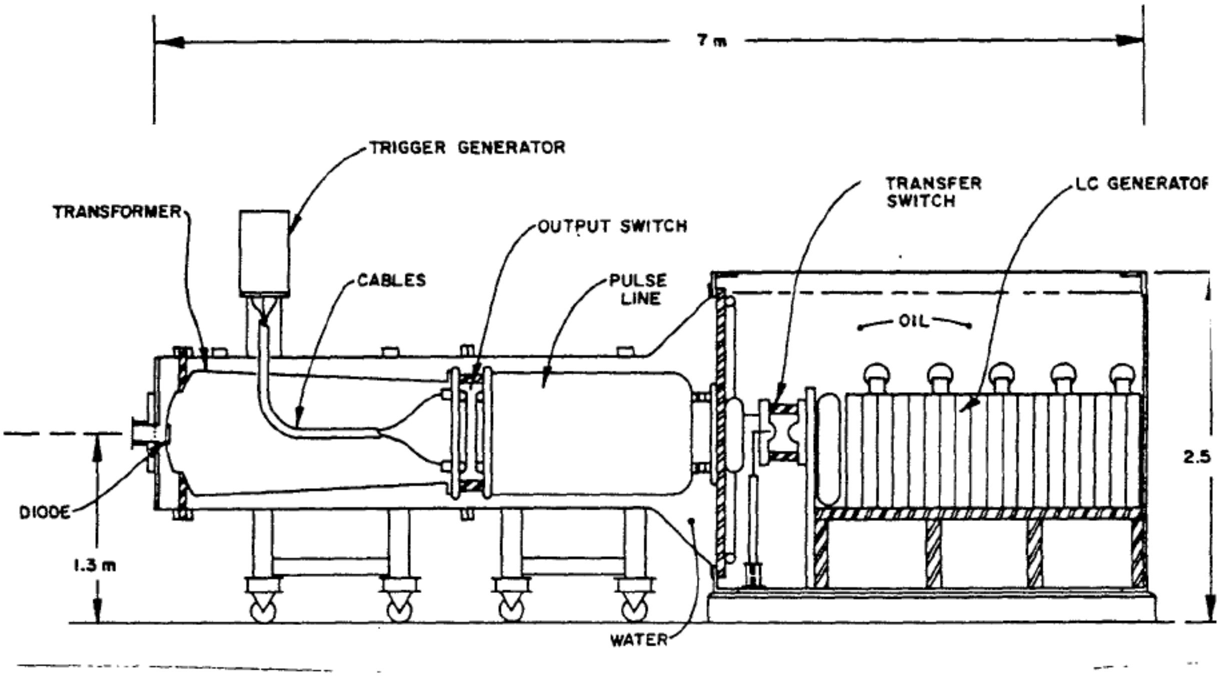

Figure 1. Sectional view of Neptune generator.

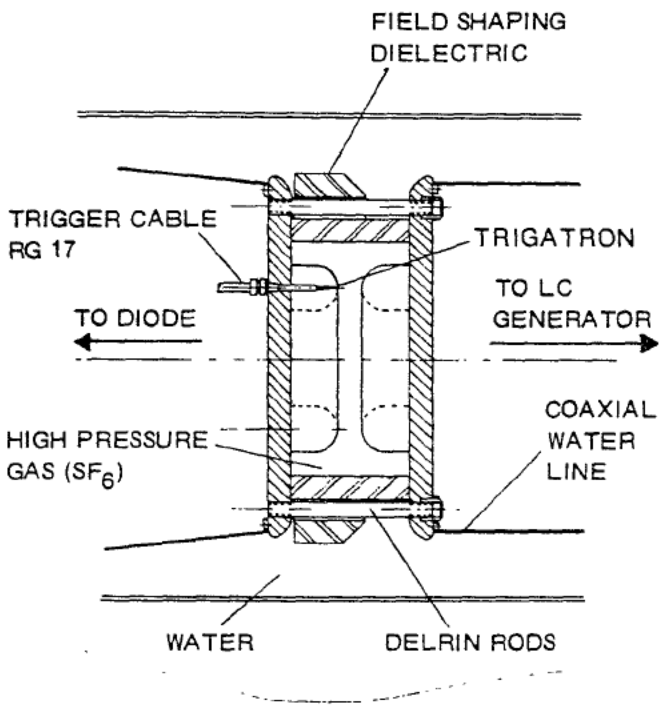

Figure 2. Sectional view of 8-channel output switch.

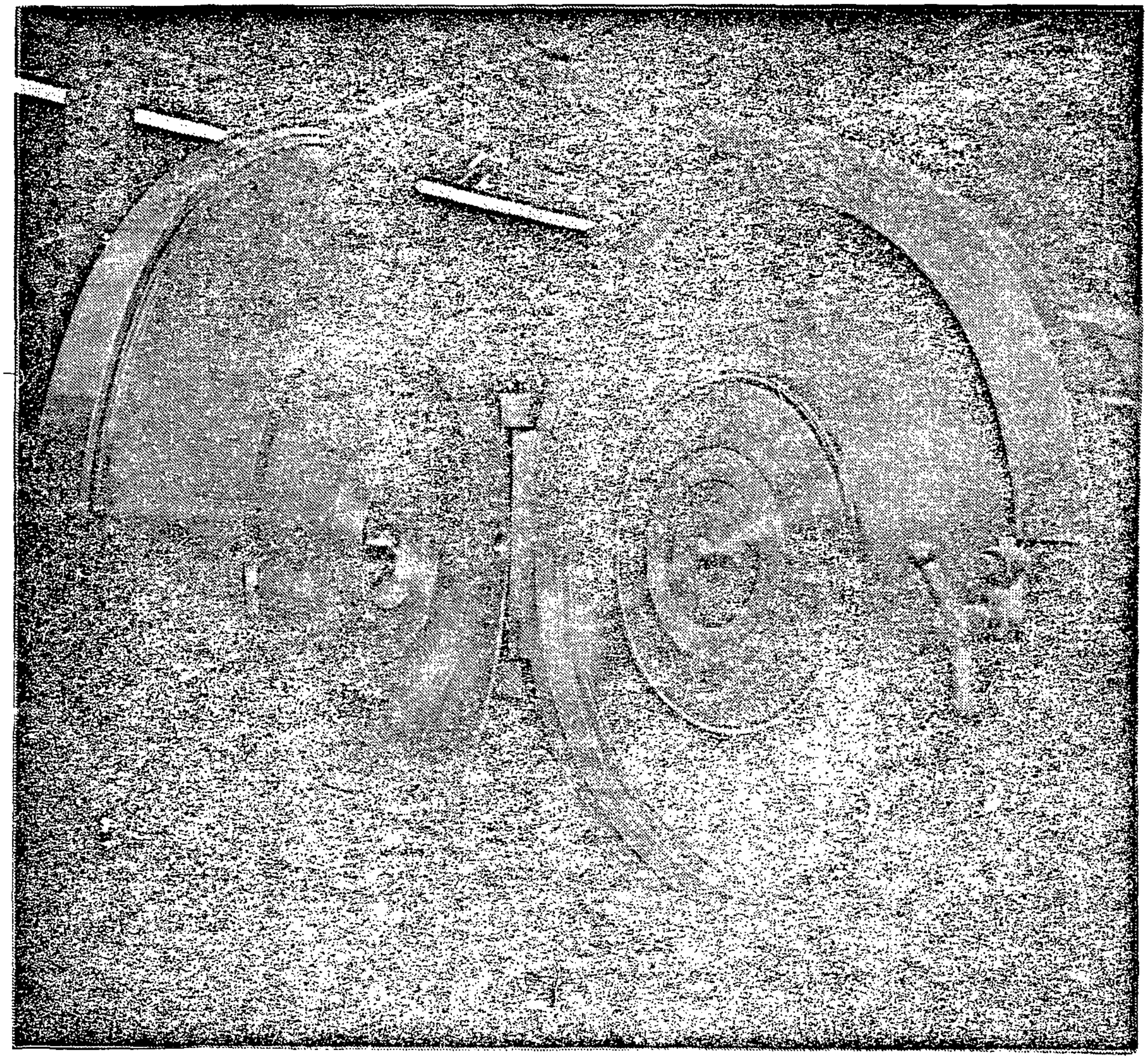

Figure 3. Photograph of diode with open hinged door.

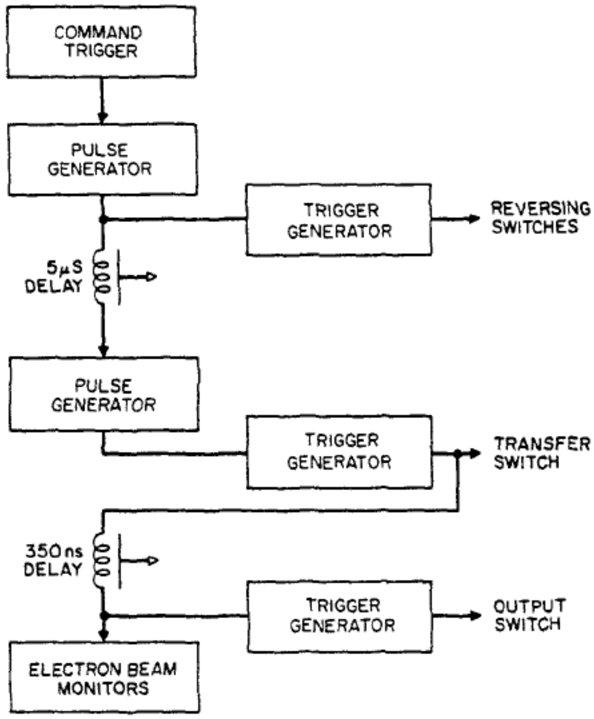

Figure 4. Control circuit.

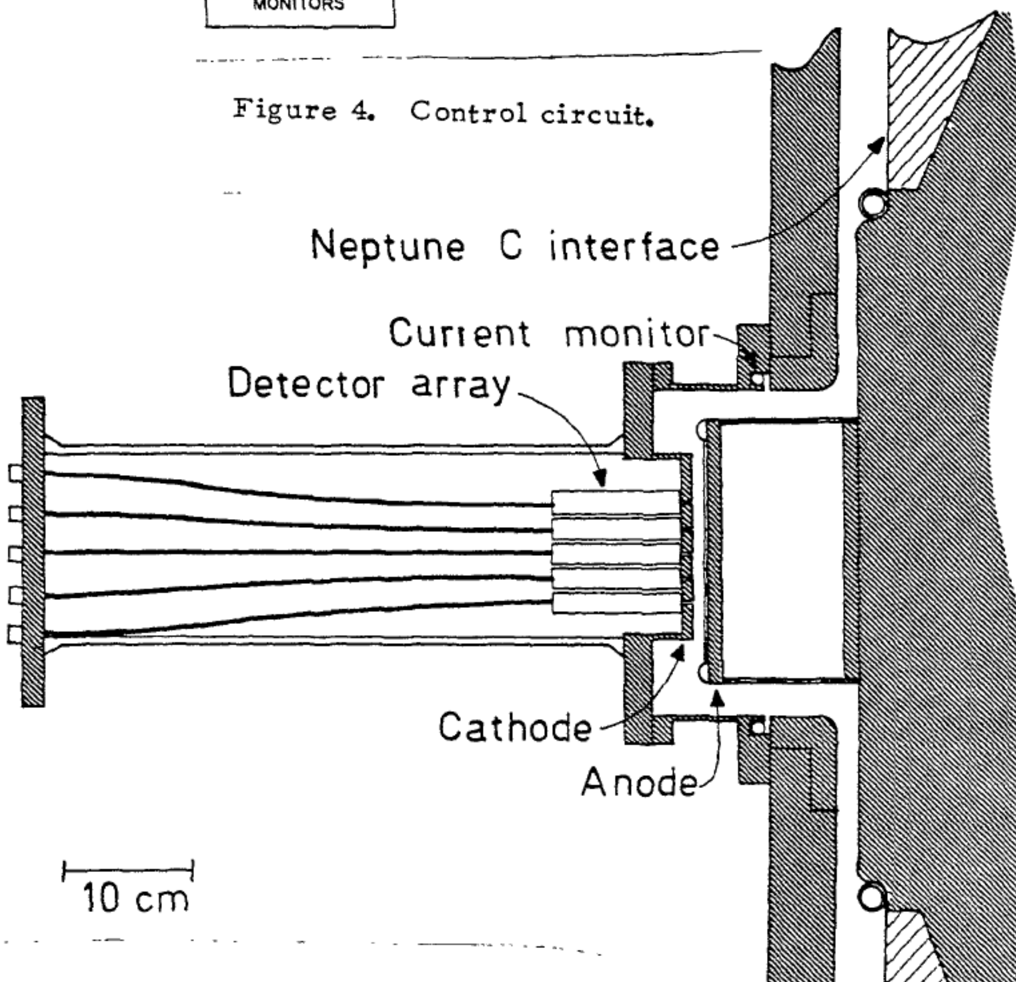

Figure 5. Scale drawing of the Neptune output with low inductance pinched diode.